TP RIO207: 4G Link Budget and BS Placement Optimization

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I. Introduction

The aim of this lab is to compute an approximate cell range for an LTE network thanks to a link budget and, based on the computed cell range, to optimize the placement of LTE Base Stations (BS) in terms of operator revenue.

II. Network Model

We aim at deploying a LTE cellular network over a given area of finite surface. The mobile operator managed to negotiate a set $\mathcal{S}$ of S sites, where Base Stations (BS) can be potentially deployed. The first phase of the study consists in computing the approximate downlink cell range R thanks to a link budget approach. The second phase consists in selecting a subset ω of $\mathcal{S}$ for effectively deploying BSs. The selection should be as optimal as possible in terms of operator revenue.

We assume that User Equipments (UE) are distributed over the network area. A UE i is said to be covered by a BS j iff $d(x_i, x_j) \leq R$, where x_i and x_j are the locations of UE i and BS j resp. and $d(\cdot,\cdot)$ is the euclidian distance. The exact value of R is determined in the first part of the TP thanks to a 4G link budget.

We assume that for budget reasons the cardinality $|\omega|$ of ω is less or equal to B_{max}. Note that the set of admissible configurations has cardinality $\sum_{b=0}^{B_{max}} \binom{b}{S}$. For example if $B_{max} = 10$ and $S = 100$, there are $1.9416e+13$ possible deployments. We adopt a very simple cost and revenue model: if a UE is covered by a BS of the operator, it generates a revenue of R_u (per unit of time); if a BS is deployed it induces an operation cost of C_b (per unit of time). Imagine that for a configuration ω, $|\omega|$ BSs are deployed and $N_{UE}(\omega)$ are covered by these BSs, then the operator revenue is given by $R_o(\omega) = N_{UE}(\omega) \times R_u - |\omega| \times C_b$. As it is impossible to perform an exhaustive search of the best solution, i.e., he one that maximizes the revenue of the operator, we will rely in the second part of the TP on a local search algorithm.

III. 4G Link Budget

A. Scenario

We consider the following assumptions:

- Limiting link: downlink
- Environment: Urban
- Carrier frequency: $f = 2.6$ GHz
- Two transmit antenna
- Transmit power (per antenna): $P_{Tx} = 46$ dBm
- Shadowing standard deviation: $\sigma = 6$ dB
- Deep indoor propagation
- Signal bandwidth: $W = 20$ MHz
- Number of HARQ retransmissions: $N_{harq} = 4$
- Cable losses of 3 dB, use of a TMA
- Outage probability: $P_{out} = 0.05$
- Approximate Shannon formula: $C \approx \alpha W \log_2(1 + SNR/\beta)$ with $\alpha = 0.75$ and $\beta = 1.25$
- Load: $\eta = 0.75$
- BS antenna gain: $G_t = 19$ dBi
- Required throughput at cell edge: $D = 3$ Mbps
- FDPS scheduling gain of 3 dB

B. Question

1) Evaluate R thanks to a 4G link budget. If some parameters are missing, make your own assumptions and justify your choices.

IV. BS Placement Optimization

A. Optimization Problem

We now study the optimization of BSs placement, by means of a Metropolis-Hastings Simulated Annealing (SA) optimization algorithm [1], with the target of maximizing the operator revenue R_o defined above. Our optimization problem is thus:

$$\arg\max_{\omega\in\Omega} R_o(\omega). \tag{1}$$

The configuration space Ω is the set of all possible subsets ω of $\mathcal{S}$ such that $|\omega| \leq B_{max}$. As we have seen before, the configuration space (though finite) can be rapidly very large even for relatively small number of sites and BSs. This means that an exhaustive search is infeasible in practice and we have to rely on other approaches. In general, the BS placement problem is known to be NP-hard [2], i.e., it is at least as hard as the hardest problems in NP.

B. Simulated Annealing

Simulated Annealing (SA) is a well-known stochastic technique for solving such large combinatorial optimization problems. It originates to in the fifties [3] but was rediscovered later in the eighties [4], and with great success in network optimization up to now [5], [6]. [7].

In our study, we consider the energy function $U(\omega) : \Omega \mapsto \mathbb{R}$, which is the inverse of the operator revenue:

$$U(\omega) = -R_o(\omega). \tag{2}$$

The principle of SA lays in assigning the following exponential probability to any configuration:

$$\mathbb{P}(\omega) = \frac{\exp(-U(\omega))}{Z} \quad \forall \omega \in \Omega \quad (\text{with } Z = \sum_{\omega \in \Omega} \exp -U(\omega)).$$

A minimizer of $U(.)$ maximizes thus the probability $\mathbb{P}(.)$ and can be found as follows:

- Initialization: assign an arbitrary initial configuration $\omega_0 \in \Omega$.
- At step $m \geq 0$: let $\omega \leftarrow \omega_m$ be the current configuration. Apply the following procedure: pick up a *neighboring* candidate configuration $\omega' \in \Omega$ and compute the following acceptance rate:

$$\Xi(\omega \to \omega') \quad = \quad \min\left(1,\ \exp - \frac{[U(\omega') - U(\omega)]}{T_m}\right)$$

  Assign $\omega_{m+1} \leftarrow \omega'$ with probability $\Xi(\omega \to \omega')$ and $\omega_{m+1} \leftarrow \omega$ with probability $1 - \Xi(\omega \to \omega')$.

Here, T_m is a *positive temperature* parameter depending on step m required to slowly decrease to 0 as $m \to +\infty$ (and rigorously to satisfy $T_m \geq \frac{T_0}{1+\log(m+1)}$). Usually a *geometric* law is adopted $T_m = T_0 \ . \ \beta^m$ with $\beta < 1$ but close to 1. We see here that if the energy is decreased, the candidate configuration is accepted with probability 1. Otherwise, the candidate is accepted with some probability that is decreasing with the energy difference. It allows the system to get out of possible local minima.

We still need the define the *neighborhood* of a configuration ω. In this work, we propose to pick at random a candidate according to three elementary operations, each with probability $1/3$:

- Add a BS: a free BS site is chosen at random and a BS is placed at this location.
- Remove a BS: a random BS is removed from an occupied site.
- Move a BS: remove a random BS from a site and add it to a free site

In the three cases, the rest of the configuration stay unchanged.

C. Scenario

We consider a squared network area of side 10 km. $N_{UE} = 500$ UEs are randomly placed over the network area in such a way that half of the users concentrate on one or two hot-spots (i.e. small areas, where the traffic load is high). There are $S = 200$ possible BS sites. The operator has decided to deploy at most $B_{max} = 30$ BSs. Every UE generates a revenue of $R_u = 1$ and every BS induces an operational cost of $C_b = 5$.

D. Questions

2) Generate random UE and BS locations according to the scenario. These locations are fixed along the SA algorithm iterations.
3) Find the optimal BS placement using SA.
4) Draw the evolution of energy, of the number of BSs and show a map of covered UEs selected BS sites and cell boundaries.
5) Propose some improvements of the model to make it more realistic.

References

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